STUDY OF GEANT4 SIMULATION FOR CYCLOTRON RADIOISOTOPE PRODUCTION IN VARIOUS TARGET SIZE

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Abstract

The application of radioisotopes in medical radiology is essential for diagnosis and treatment of cancer. The fabrication of radioisotopes has main factors that maximize the fabrication yield and minimize the costs. An effective method to solve this problem is that the usage of Monte Carlo simulations before experimental procedure [1]. This paper studies the simulation and presents cyclotron models for the energy 13 MeV with moderate beam intensity are used for production of 11C, 13N, 15O, and 18F isotopes widely applied in positron emission tomography [1]. TR-13 cyclotrons with high beam intensity are available on the market for production of most medical and industrial isotopes. In this work, the physical and technical parameters of different models are compared. Overall, this confirms the applicability of Monte-Carlo to simulate radionuclide production at 13 MeV proton beam energy.

INTRODUCTION

Compact cyclotron is normally used to produce for short-term lived radioisotopes, especially using applications for positron emission tomography (PET) [1, 2]. These kind of machines accelerate protons and also produce four positron emitters that are carbon-11, nitrogen-13, oxygen-15 and fluorine-18. The four positron emitters are easily produced by the low-energy and nuclear reactions. Normally, the methods of productions about these emitters use gas and liquid targets for employing. In addition, many medical cyclotrons are adopted both two target systems, which are generally attached directly to cyclotron. It is suitable to produce radioisotopes by using targets systems, however it didn't be optimized sufficiently about thickness with materials [2].

In this study, the Monte-Carlo simulation code Geant4 is used for optimization of target thickness as well as target materials that role as a critical assessing the yield for isotope production of system. It is a typically calculation tool that suggests particle tracking and interaction with mass. And also, it can provide wide range of applications, which is target design, calorimetry, activation and dose rate measurement. To get results harmoniously, we set out to use Geant4 to calculate following hadronic reactions for nuclear and particle physics for carbon-11, nitrogen-13, oxygen-15 and fluorine-18.

DESIGN AND SYSTEM DESCRIPTION

Geant4 is open source code, which is Monte Carlo toolkit for the tracking particles through matter. It is often used that applicate physics and medical field with various area. This simulation tool is suitable for evaluation of irradiation of target system with a large data driven physics models [1].

The simulation model is the target system of the SKKUCY-13 cyclotron. The geometry is based on a simple drawing of the system. The target system is made of cylindrical shape target chamber and target body that can modulate the energy of the beam and a target at the end of the fixed chamber. Fig.1 shows the geometry for simulation to calculate radioisotopes production. The target is made for optimization of target shapes which allows the selection of the thickness. The proton beam line passes through the tube with foil before hitting the target. This schematic drawing geometry model is generated to calculate for target configurations with adopted various thickness system.

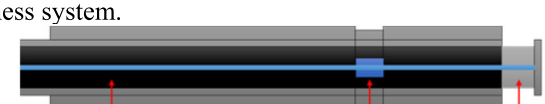

Figure 1: Geometry for radioisotope production target system.

In this paper, a further investigation has been performed via the low-energy (p, n) and (p, α) nuclear reactions cross section values for energies at 13 MeV using the TENDL library [1, 3].

To calculate the cross section values, several simulations were run using different chamber thickness and a thin 11C, 13N, 15O and 18F target in target chamber, so the energy would remain approximately constant while the proton would travel through the target. To achieve reasonable computing time, sensitive volume (the target chamber) was defined to track particles in the regions of interest. On average, around 10000 events were necessary to achieve good precision. This represents around one hour of simulation on a general purpose processor.

RESULTS AND DISCUSSIONS

The isotope number of reactions relative to ^{11}C, ^{13}N, ^{15}O and ^{18}F production were also compared to theoretical results of P. W. Schmor et al [4]. The relative simulated

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result shows the comparison of number of reaction and mean energy at 13 MeV. It shows an overestimated trend in Fig. 2.

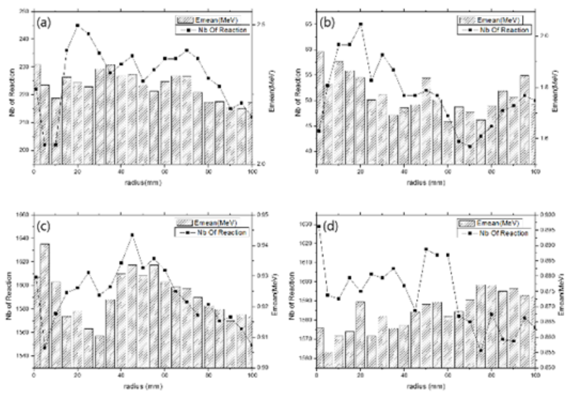

Figure 2: Number of Reactions and mean Energy for (a) ^{11}C, (b) ^{13}N, (c) ^{15}O and (d) ^{18}F at thickness range from 1 mm to 100 mm.

As the target is thick, the protons have an energy of 13 MeV when they leave it, which explains why over a large thickness range the results show an overall underestimation. However, the target radius varies between 1 to 100 mm within the target and as Fig. 2 shown. Also the expected conclusion can be explained by some inaccuracy from cross section.

For simulations with thick targets with energy 13 MeV, there is a systematic overestimation of the yield compared to theoretical results at various thicknesses. The overestimation of the cross section at thin thickness is more dominant than the underestimation at high energies, resulting in an overestimated yield when integrating over a large thickness range.

The cross section of the reaction was calculated through the simulation using the QGSP_BIC_AllHP physics model and the TENDL library, with energies 13 MeV. The first step was to verify that the cross section outcome from the simulation was the same as the TENDL cross section that is used. As shown in Fig. 3, they were in reduced value with some error due to the uncertainty of the simulation.

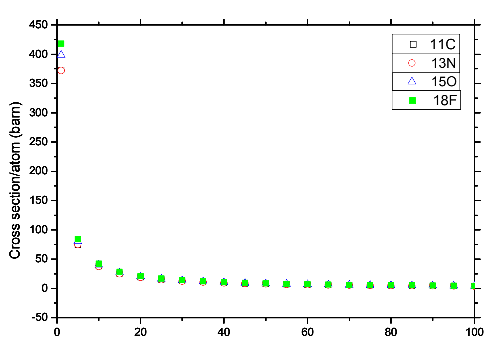

Figure 3: Production yield calculation result for (a) 11C, (b) 13N, (c) 15O and (d) 18F at various thicknesses.

The results from the simulation are shown in Fig. 4 and compared each isotopes results. The graph shows good agreement each isotopes cross section simulation results. However the simulation cross section values tend to be decline at energy 13 MeV. Figure 4 shows production yields for different radius ranges for Geant4 simulation. Overall, the simulation tends to overestimate the saturation yield with 103 ± 10 mCi/μA for 11C a thickness range from 1 to 100 mm, with protons reaching the target with an energy of 13 MeV. The theoretical yield is 100mCi/μA and the simulated yield is 103 ± 10mCi/μA, giving an overestimation of 10% compared to theory. When comparing theoretical yield and simulated yield, it is interesting to note that for a thickness range from 1 to 13 mm the simulation overestimates the yield.

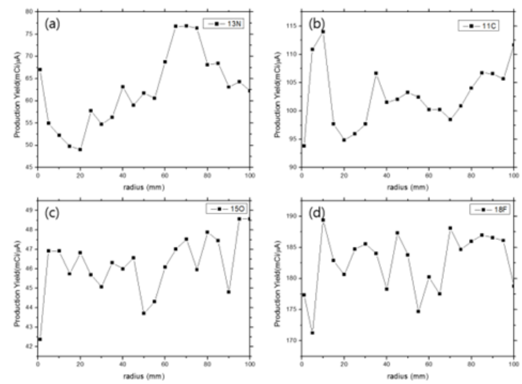

Figure 4: Cross section for each isotopes at various thickness range.

For a whole range of thickness, the theoretical yield and the simulation yield are in good agreement. This difference can be attributed to particle transport, which plays a larger role when working with a thick target. The asymmetry observe in various thickness can be explained by the fact, which leading to the results can compared between theoretical and simulated for each isotopes.

CONCLUSION

A GEANT4 toolkit for simulation of a medical cyclotron solid beamline has been developed and described in details. An example study with 11C, 13N, 15O and 18F was performed and results presented [5, 6]. Agreement between simulated yields and theoretical yields varied with reaction types. The accuracy of the simulation is subject to the quality of nuclear data files and libraries employed. A major advantage of the Monte Carlo toolkit described in the current work is the ability to study contamination isotope species for the purpose of radiation safety [7, 8]. The physics model used has just been included in the Geant4 version 10.1 and is not yet matured. Further refinement of the QGSP_BIC_AllHP physics models and nuclear database files may result in closer agreement with experimental studies.

While initial results are promising, the test cases are limited and more extensive results must be obtained to validate other target material irradiations. With further validation, the toolkit promises to be a powerful tool for studying the performance of medical cyclotron isotope

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production for both contamination and radiation safety monitoring. Furthermore, this is a cost efficient approach to studying new isotope production mechanisms before investing in costly experimental studies [9]. We expect to include in GEANT4 in the near future the described software as an example where further development will be possible. All the features exposed in the paper such as the GUI will be available in open source access. A user guide will be provided, allowing users unfamiliar with the Geant4 C++.

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